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16. Abstract

Silicate inclusions and impact metamorphic features in the El'ga meteorite, found in 1958 at Yakutia, are discussed. The chemical composition (oxides and number of cations per element scaled on the basis of six and eight oxygens) of the primary minerals forming the inclusions (K-Na-feldspar, clinopyroxene, and others) was determined, as well as changes observed in the meteorite with features of shock metamorphism typical for iron meteorites.

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SILICATE INCLUSIONS AND IMPACT METAMORPHISM FEATURES IN THE EL'GA OCTAHEDRITE

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The El'ga meteorite found in 1958 in Yakutia (Meteoritnyy /143* byulleten', 1960; Plyashkevich, 1960; Vronskiy, 1962) belongs to the small number of iron meteorites currently known that contain silicate inclusions. It was studied and identified as a fine-structured octahedrite with silicate inclusions of a composition that is unusual for meteorites and with deformation textured sections (Plyashkevich, 1960, 1962). The metallic part of the meteorite was chemically analyzed many times (D'yakonova, Kharitonova, 1963; Wasson, 1970).

Silicate inclusions amount to 10-15% of the volume of the meteorite. Their primary minerals, as L. N. Plyashkevich demonstrated, are K-Na-feldspar (anorthoclase ?), the first such feldspar reliably determined at that time in meteorites, maskelynitized in places, and clinopyroxene related to pigeonite, but appearing to be chrome-diopside (Table) in nearly equal quantities. Hortonolite, merrillite, glass, isolated oligoclase, chromite (?), lawrencite (?), not counting troilite and schreibersite, were noted from admixtures in them. A number of features of the meteorite structure were also noted.

Our problem was to determine the chemical composition of the primary minerals that form the silicate inclusions, and, in addition,

*Numbers in the margin indicate pagination in the foreign text.

to compare the changes observed in the meteorite with features of shock metamorphism.

Silicate inclusions in our investigations were scanned under a microscope on polished surfaces from a sample of the El'ga meteorite from the collection of the Committee on Meteorites of the USSR Academy of Sciences (sample No. 2315; photogram 1a, b)*and in transparent sections (with area rarely more than 1-2 mm^2) prepared from fragments of separate silicate inclusions. The most dispersed silicate inclusions were for the most part represented in them, which was possible to conclude in comparing their textures and that of the silicate inclusions observed on polished surfaces under a microscope.

Their shape was mostly irregular, but always with rounded contours, sometimes drop-like and occasionally regularly spherical. In contrast to most of the inclusions, which reach 15 mm in length and which are generally dark in hue, the cross section of the observed inclusions of regular spherical shape does not exceed 5 mm, and they have a light almost milk-white color. Chinks and stringers of the same composition as them often branch out from the silicate inclusions. The silicate inclusions frequently consist of a thin, often discontinuous, mantle of schreibersite.

Chemical Composition of Minerals from Silicate Inclusions (wt.-%) **

Oxide	K-Na-feldspar (six grains)	Cr-hydropside (five grains)	Bronzite (four grains)
SiO_2	69,5	55,4	57,7
TiO_2	0,31	0,30	0,25
Al_2O_3	17,8	0,97	0,25
Cr_2O_3	0,03	1,31	0,39
FeO	0,36	5,54	11,6
MnO	[illegible]	0,12	0,22
MgO	0,16	17,3	29,9
CaO	0,58	20,0	1,02
Na_2O	8,78	0,61	0,10
K_2O	2,40	—	—
Total	99,89	101,55	101,43

*Translator's Note: Not included in this translation.
**Translator's Note: Commas represent decimals.

Number of cations scaled on the basis of

Element	Eight Oxygens	Six Oxygens	
Si	3,051	1,989	2,008
Al^{IV}	0,923	0,011	—
Al^{VI}	—	0,032	0,012
Ti	0,011	0,009	0,006
Cr	—	0,037	0,010
Fe^{2+}	0,013	0,166	0,336
Mn	—	0,002	0,006
Mg	0,011	0,926	1,552
Ca	0,029	0,770	0,038
Na	0,749	0,043	0,008
K	0,132	—	—
Sum of cations	4,919	3,985	3,976
f (Fe/Fe + Mg)		15,2	17,8
Ca/Ca + Mg		45,4	2,4
Cr/Cr + Al		46	45

Most of the silicate inclusions are made up of clinopyroxene /144 and significantly less orthopyroxene and alkali feldspar, often either displaced entirely or partially by a pure transparent isotropic matter. The characteristic texture of these silicate inclusions is shown in photogram 1c. Often, small prisms are located along the boundaries of, as well as tangentially to, eccentrically radiated bundles from similar prisms of clinopyroxene, while the marginal zone of the inclusions is composed of alkali feldspar.

Clinopyroxene is a chrome-diopside (see Table) usually in small prisms, of a superficial greenish hue, fissured, with fine polysynthetic twins in places, and with a sharp cleavage along (001).

The crystal-optical constants of clinopyroxene obtained in this study (which are close to the data obtained by L. I. Plyashkevich for clinopyroxene and other minerals) are as follows: $2V = +60°$; $C{:}\,Ng = 44°$; the mineral often darkens inhomogeneously; $Ng = 1.705 \pm 0.002$; $Nm = 1.694 \pm 0.002$; $Np = 1.677 \pm 0.002$. Orthopyroxene is significantly less than clinopyroxene, and it is in larger prisms (up to 0.7 mm in length and 0.07 mm in width) than clinopyroxene. It is close to clinopyroxene in refraction, /145 differing from it by parallel extinction and by low birefringence. The central part of its grains is sometimes composed of clinopyroxene in the form of grains extended along the vertical axis and lacking crystallographic contours. Pyroxenes are embedded in an aggregate from lengthened xenomorphic grains of K-Na-feldspar having the structure of spherical crystals with the center of crystallization located at the narrow end of the grain. They usually form radial aggregates of pinnate form. Alkali feldspar is brownish in hue, darkened with fine inclusions. A typical fracturing in the form of a system of parallel arched fissures similar in places to a cleavage can be seen in it. Its optical constants are: $Nm = 1.528 \pm 0.003$; $Ng = 1.533$; 2V was difficult to measure, but it seems to exceed 60° and is negative (cf. the data of L. I. Plyashkevich).

This alkali feldspar is morphologically, optically, and chemically very close to alkali feldspar from the silicate inclusions of the Kodaikanal meteorite, described upon its discovery as a new mineral, rich in alkalis, aluminum oxide, and iron, namely weinbergerite (Berwerth, 1906), though later, when it became possible to apply the X-ray diffraction method for studying it, it turned out to be a submicroscopic mixture of alkali feldspars, namely cryptoantiperthite (Olsen and Mueller, 1964; Bunch and Olsen, 1968; Bunch et al., 1970).

It has not been possible with micro probing to establish a submicroscopic structure, i.e., the presence of two phases, in alkali feldspar of silicate inclusions of the El'ga meteorite, though some inhomogeneity has been noted in it.

In some inclusions an isotropic substance plays the role of K-Na-feldspar (photogram 1d). Morphological features are seen in them that are similar to those in K-Na-feldspar, namely: the same nature for the boundaries of the grains and the boundaries with pyroxenes, the nature of the fracturing, the presence in places of turbid sections or very fine needle-shaped inclusions. Its index of refraction N is 1.502 $\pm$ 0.002. Unfortunately, the isotropic substance was not found in the specimen that underwent X-ray diffraction microprobing, and its chemical composition remains to be determined, though according to its index of refraction there is about 70% SiO_2 in it, which corresponds to the SiO_2 content in the K-Na-feldspar investigated. According to these properties, the isotropic substance can be defined as maskelynite, or, more accurately, as K-Na-maskelynite in the opinion of Milton and De Carli (1963), i.e., as an uncrystallized phase that is a pseudomorphosis via crystallized feldspar formed by means of a reversion to the solid state as a consequence of the effect of shock waves.

Fragments isolated from one of the spherical inclusions with a cross section of about 3 mm were studied in embedded specimens. They turned out to be a complex isotropic substance with N = 1.490 $\pm$ 0.002, colorless, permeated with very fine small needles of a high-refractive and high-birefringent mineral, possibly rutile (?). In this case, it is possible to compare the texture and composition of this inclusion with similar features of certain silicate inclusions of the Kodaikanal meteorite, composed of glass overflowing with rutile and hence called 'rutilized' glass (Bence and Burnett, 1969).

The compositons of the primary minerals of silicate inclusions were determined by the M-46 X-ray diffraction microanalyzer under conditions described earlier (Sobolev, V. C. et al., 1969; Sobolev, N. V. et al., 1969). The relationships of intensities measured were corrected for absorbtion of X-ray radiation in the samples (Philibert, 1963), for the influence of the atomic number of the radiator (Duncumb, Reed, 1968), and for fluorescence from the characteristic spectrum (Reed, 1965). The results of the investigation are presented in the table.

K-Na-feldspar is a rare meteorite mineral. The content of trace elements in it is similar to their content in K-feldspars from inclusions of other meteorites (Bunch, Olsen, 1968). Some inhomogeneity was established in the grains studied, while the K /146 and Na content varied together. Chemically it belongs to anorthoclase (Dir et al., 1966).

The clinopyroxene contained an increased admixture of chromium and may belong to chrome-diopside. The increased content of chromium, together with the increased ferruginosity distinguishes its composition from the most wide-spread clinopyroxene silicate inclusions of iron meteorites. The reduced calcicity of diopside, implying the presence of a solid solution of enstatite, is also noteworthy.

Orthopyroxene is a bronzite and is characterized by the presence of chromium titanium and an insignificant trace of Al_2O_3 in it. It was noted that the chromicity of Cr/(Cr + Al) and its ferrugenosity and that of diopside are the same (see the Table).

A comparison of the data obtained with the data of an investigation of silicate inclusions of other iron meteorites (Bunch et al., 1970) shows that inclusions of the El'ga meteorite can be referred for paragenetic congruity and composition of minerals to the least widespread of the Weekeroo Station type. The silicate inclusions of the El'ga meteorite and the Kodaikanal meteorite found in 1889 in India are especially similar, as are these meteorites on the whole. Both fine-structured octahedrites are similarly variable (Berwerth, 1906; Bence and Burnett, 1969). We have already spoken of the similarity of alkali feldspars of silicate inclusions of these meteorites.

If we examine silicate inclusions of the El'ga meteorite (bearing in mind the insufficient completeness of its analysis) in terms of the distribution of Fe and Mg in the pyroxenes as an association close to equilibrium, then, by assessing the composition of diopside with a reduced Ca/(Ca + Mg) ratio, it is possible to estimate the equilibrium temperature of the minerals as close to 1000°C (Boyd, Schairer, 1964), and to relate them to the highest temperature minerals among those investigated (Bunch et al., 1970).

The features of the fine-octahedritic El'ga meteorite were described and illustrated with photogrpahs (Plyashkevich, 1960, 1962, Figs. 3-9). Among the features noted were nonhomogeneity of the total structure: separation of sections, local development of deformations and of distinctive textures in the nickel iron, such as ripples, pinnation, sharp striations, and deformations of the Neumann lines in the kamacite beams; fine-eutectic and porous troilite, and fracturing of the schreibersite. The nature of these changes has been explained in an entirely justified manner as a consequence of secondary fusion. In our samples an acicular-martensite-like kamacite structure, zones of finely flared metal, near which kamacite is secondarily granulated, and strong fragmentation of schreibersite, especially near the silicate inclusions, were additionally noted. These changes, as is now known, serve as features for shock metamorphism of iron meteorites (Lipschutz, 1968 and others).

In our case the relationships between K-Na-feldspar and the isotropic matter can be explained by shock metamorphism, taking into account the possible (Bence and Burnett, 1969) partial reversion of K-Na=feldspar to an isotropic substance (K-Na-maskelynite). The peculiarity of K-Na-feldspar, however, requires further investigations.

Thus, the changes noted in the fine-octahedritic texture of the El'ga meteorite and the minerals in its silicate inclusions can, based on contemporary data, be related through the shock metamorphism which the meteorite evidently underwent.

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